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14. ABSTRACT
Automated biomonitoring systems provide continuous, real-time monitoring of changes in water quality and can rapidly identify toxicity associated with a wide range of chemical contaminants while increasing public confidence in drinking water quality. Biomonitor use is widespread in Europe but rare in the United States. This paper illustrates how biomonitors can contribute to an early warning monitoring system for source and finished water protection using case studies of a biomonitor that continuously monitors the fish ventilatory patterns integrated with basic water quality parameters. At two water utilities, the biomonitor was operational $\geq$ 96% of the time. Toxicity alarms occurred for a small diesel oil spill and a probable agricultural chemical release. The case studies provide a context for a discussion of considerations important for biomonitor implementation, including: toxicant responsiveness, event confirmation, implementing biomonitors in a decision-making process, and costs. Recommendations are provided for biomonitor use at raw water intake and in distribution systems.

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Automated biomonitor, biomonitor, drinking water, early warning, source water, water distribution system, toxicity

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Automated biomonitoring systems provide continuous, real-time monitoring of changes in water quality and can rapidly identify toxicity associated with a wide range of chemical contaminants and increase public confidence in drinking water quality. Although widespread in Europe, biomonitor use is rare in the United States. Using case studies of a biomonitor that continuously monitors fish ventilatory patterns, this article illustrates how biomonitors can contribute to an early warning monitoring system for source and finished water protection. The case studies provide a context for a discussion of considerations important for biomonitor implementation, including toxicant responsiveness, event confirmation, implementation of biomonitors in a decision-making process, and cost. Recommendations are also provided for biomonitor use at raw water intake and distribution systems.

An online real-time biomonitor for contaminant surveillance in water supplies

BY YVES B. MIKOL, WILLIAM R. RICHARDSON, WILLIAM H. VAN DER SCHALIE, TOMMY R. SHEDD, AND MARK W. WIDDER

Protecting drinking water sources from chemical contamination is an area of increased concern in recent years. Although federal and state agencies do not mandate that water utilities monitor raw water in real time, many water suppliers have adopted a proactive approach (Gullick et al, 2003; Schreppel, 2003; Grayman et al, 2001; Stoks & Penders, 2001). The desire for rapid identification of adverse water quality changes is evident in the development of early warning systems for both individual water utilities and regional source water protection (Gullick et al, 2004; Grayman et al, 2001; Gunatilaka & Diehl, 2000; ILSI, 1999).

Early warning monitoring systems for source waters can provide rapid detection of accidental spills originating from nonpoint sources or point sources such as wastewater treatment plants, transportation incidents, and deliberate contamination events. Early warning information can improve decision-making, reduce risks, increase public confidence, and encourage good practices by dischargers (Stoks & Penders, 2001; ILSI, 1999). Most early warning systems at water utilities rely on analytical identification that is often preceded by concentration and extraction. However, providing continuous, real-time monitoring to rapidly identify specific chemical contaminants in water is difficult (ORSANCO, 2005; ILSI, 1999).

Using online systems for comprehensive analyte-specific determinations requires expertise and is labor-intensive, considering the instrumentation required for evaluating different classes of chemicals such as polar and nonpolar organics, metals,

and ionic compounds. Monitoring simple water quality parameters such as residual chlorine or turbidity, although inexpensive, cannot detect many chemical spill events (Gullick et al, 2003), and no analytical chemistry technique can directly measure toxicity. Toxicity can only be inferred by comparing measured chemical concentrations with toxicity benchmarks, such as established water quality standards, and this approach does not effectively address chemical-mixture toxicity.

ONLINE BIOMONITORS

Biological techniques that directly measure toxicity complement traditional physical and chemical measurements. Rapid toxicity tests for evaluating individual water samples have been recommended to assist in drinking water security investigations (States et al, 2004), and online biomonitoring systems are available commercially for the continuous monitoring of water supplies (Stoks & Penders, 2001; ILSI, 1999). The concept of biomonitoring was proposed more than 40 years ago (Henderson & Pickering, 1963), and some utilities even today use manual observation of fish in tanks as a method of identifying water quality problems. However, this approach sacrifices sensitivity (higher toxicant concentrations may be required to cause visually evident changes) and immediate notification of problems (unless someone is observing the fish at all times). The availability of relatively low-cost electronic components has allowed the development of automated biomonitors that can provide continuous, real-time monitoring.

Online biomonitors rapidly identify toxicity associated with a broad range of organic and inorganic chemicals by continuously monitoring changes in the behavior or physiological responses of aquatic organisms. A variety of aquatic organisms is used in commercially available biomonitoring systems (Table 1).

Biomonitors offer a number of advantages for source water protection.

- They can respond rapidly to a range of contaminants. Living organisms will respond to any chemical in water if the concentration and exposure time exceed the organism's response threshold for the endpoint being monitored. Response times decrease with increasing exposure concentrations (Diamond et al, 1988).
- They are versatile and can be used in a number of water monitoring applications. In addition to source water and distribution system protection, biomonitors can be used for effluent monitoring (Shedd et al, 2001) and watershed protection (USEPA, 2001).
- When automated, they provide continuous monitoring. When used for source water evaluation, biomonitors that operate continuously can alert system operators to potential problems as they occur, thus allowing one person to be responsible for several monitors and assuring water quality managers and consumers that good water quality is maintained (Bode & Nusch, 1999).

The potential benefits of biomonitors must be balanced against other considerations. For example, biomonitors do not identify the specific chemicals causing a response, and they can respond to some water quality conditions that are not harmful to humans. This article illustrates how biomonitors can contribute to an early warning monitoring system for source water protection. Case studies involving a biomonitoring system that continuously monitors the ventilatory patterns of fish (van der Schalie et al, 2001) are described for both a large system and a small system. The case studies provide a context for a discussion of the considerations important for implementing a biomonitoring approach and offer recommendations for biomonitor optimization.

AQUATIC BIOMONITOR OPERATION

The aquatic biomonitor used at both source water facilities in the case studies identifies potentially toxic events by continuously monitoring for rapid changes in the ventilatory and movement patterns of the bluegill (*Lepomis macrochirus*). Before their use in the biomonitor, the fish are maintained on site in a holding tank. Appropriate animal care procedures are essential, and animal rights issues may be a concern (Gerhardt, 1999; LAWA, 1996).

TABLE 1 Examples of responses measured in aquatic biomonitors

Organism	Parameter(s) Monitored	Reference
Fish	Ventilatory movements, swimming movements, electrical organ discharge	Shedd et al, 2001; Blübaum-Gronau et al, 2000; Thomas, 2000
Daphnids (water fleas)	Swimming movements	Gunatilaka et al, 2000; Lechelt et al, 2000
Clams	Valve closure	Kramer & Foekema, 2000
Benthic invertebrates	Movement	Gerhardt, 1999
Algae	Fluorescence	Gunatilaka & Diehl, 2000
Bacteria	Fluorescence	Gerhardt, 1999

Eight fish are held in individual chambers under flow-through conditions (Figure 1) and in continuous light (to minimize daily variations in ventilatory patterns). Electrical signals generated by muscle movements of individual fish are monitored by carbon block electrodes suspended above and below each fish. The electrical signals are amplified, filtered, and passed onto a personal computer for analysis. Each input channel is independently amplified by a high-gain true differential-input instrumentation amplifier. Signal inputs of

0.05–1 mV are amplified by a factor of 1,000. Signal interference by frequencies above 10 Hz is attenuated by low-pass filters. The computer provides signal amplification by an additional factor of 10.

Ventilatory parameters measured include ventilatory rate, ventilatory depth (mean signal height), gill purge (cough) frequency, and whole body movement (rapid irregular electrical signals). Each parameter is calculated at 15-s intervals, and any interval containing whole body movement is excluded from the calculation of the other three parameters. The 15-s intervals are added to create a 15-min data record. Further details of specific algorithms are described elsewhere (Shedd et al, 2002). Test methods are similar to those described in van der Schalie et al (2001).

In addition to fish ventilatory data, conductivity, dissolved oxygen, pH, and temperature are monitored during the same 15-min intervals as the fish using commercially available water quality multiprobes.[1] These data help determine whether fish responses are because of the presence of toxicants or because of nontoxic water quality variations.

Two statistical approaches have been used to identify abnormal fish ventilatory and movement patterns. One method is a statistical control chart approach in which data are collected from each fish during a four-day pre-exposure (baseline) period to establish normal limits for each parameter monitored (van der Schalie, et al, 2001). If during the subsequent exposure period a parameter is found to be statistically different from the normal (baseline) response, the response is said to be "out of control." A biomonitor alarm occurs when more than 70% of the fish (e.g., six or more of the eight fish in the monitoring chamber) are out of control in the same 15-min interval.

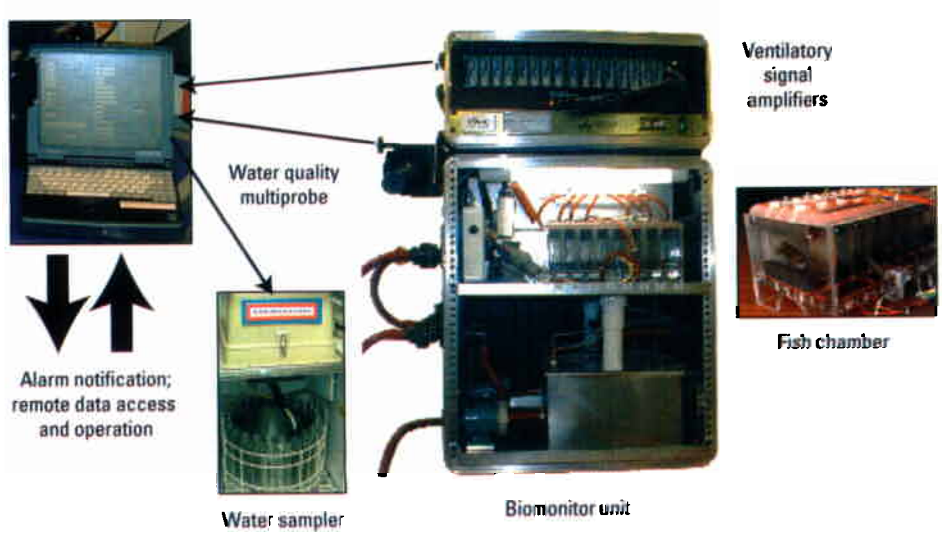
A second statistical approach uses a neural net expert system[2] that analyzes both fish behavioral patterns and basic water quality information (e.g., temperature, dissolved oxygen, pH, and conductivity) to determine abnormal fish behavior (Wroblewski, 2004). The neural network was trained using data sets from hundreds of bluegills previously monitored under laboratory and field conditions. For every 15-min monitoring interval, a toxicity index value is generated for each fish. If an individual fish has a toxicity index value > 1, it is considered a "novel event." As with the control chart-type statistical approach, if more than 70% of the exposed fish have novel events in the same 15-min interval, an alarm response is generated.

The expert system approach has several advantages over the control chart approach. For example, in the expert system approach, fish require only one day of acclimation and no baseline period, which increases by six days the amount of time a fish can remain online. Also the expert system does not show increased alarms with increasing time after the baseline period caused by drift in the fish signal patterns. In most cases, when the same biomonitor data are analyzed by both methods, the expert system responds as rapidly or more rapidly to toxic events than the control chart approach. The expert system has now replaced the control chart approach for all applications of this biomonitor.

The biomonitor system[3] configuration is shown in Figure 1. Water to be monitored flows into the recirculation chamber and is pumped up to the fish chambers. The computer monitors fish ventilatory and movement patterns and water quality data from the multiprobe. If the biomonitor or the water quality probe alarms, the computer turns on a refrigerated water sampler[4] and uses an autodialer[5] to notify the appropriate individuals. (E-mail notification is now possible with the expert system software.) Data and system operation can be monitored remotely via software[6] through a phone connection or through intranet/internet in the expert system.

One set of eight fish can be used in the biomonitor for three weeks. Continuous monitoring without interruption is achieved through the use of a second set of eight fish

FIGURE 1 Aquatic biomonitor



(held in the rear of the unit, not visible in Figure 1). Additional fish are kept in holding tanks. Before removing the first set of fish, the second set of fish is added to the second monitoring chamber and allowed to acclimate for 24 h (72 h when the control chart method is used). After acclimation (acclimation plus the baseline period for the control chart method), the second set of fish is put online, and the first set of fish is returned to the holding tanks. The same protocol can be used for finished water.

In addition, the simultaneous use of the biomonitor's two monitoring chambers allows for the monitoring of source water intake and finished water (downstream from the water treatment plant). This configuration was used in the small system case study. Because residual chlorine is toxic to aquatic life, the finished water was first treated using a dechlorination system[7] that adds a small amount of sodium bisulfite to the water flowing into the biomonitor (van der Schalie et al, 2005).

The availability of relatively low-cost electronic components has allowed the development of automated biomonitors that can provide continuous, real-time monitoring.

The main disadvantage of the simultaneous use of both chambers is that there is a gap in monitoring every three weeks while a new batch of fish is acclimating to the new chamber environment. Although mortality can be identified during the acclimation period, alarms because of physiological responses short of death are unreliable during the first 4 h of acclimation, and they are of marginal use until 24 h have elapsed when the expert system is used.

CASE STUDIES

Large system. Approximately 17,000 residents live in the 570 sq mi of this predominantly forested and agricultural watershed feeding the reservoir. Flow at the effluent averages 300 mgd. The source water is low in hardness and conductivity (Table 2). Annual source water quality variations are minimal (except for temperature), and most changes occur slowly over a period of days. The biomonitor received untreated water from the reservoir effluent.

The control chart-type statistical approach was used between October 2002 and July 2004. During this time, the biomonitor was operational 96% of the time. Of the 4% downtime, 1% was because of routine issues such as test initiation and data archiving. The remaining 3% of downtime was because of computer/operating system crashes and water quality multiprobe maintenance. Biomonitor system maintenance and care of the fish in holding tanks required approximately 4 h per week.

Biomonitor alarms were rare during the case study period. Sudden temperature fluctuations, physical disturbances of the fish, and drift in fish signal patterns with time triggered occasional alarms, which were classified as nontoxicant-related. The control chart statistical approach produced more nontoxicant-related fish alarms with increasing time after the baseline period. When an alarm occurred, the biomonitor data could be accessed remotely to investigate the cause of the alarm.

A water quality event occurred while the reservoir effluent was offline as a result of construction occurring near the effluent being monitored. The biomonitor autodialer called in an alarm at 9:00 a.m. on May 27, 2003 (Figure 2). The water quality parameters monitored (pH, dissolved oxygen, temperature, and conductivity) were within normal ranges and had not changed appreciably during the time leading up to the alarm. There was no indication of equipment failure or disturbance to the biomonitor. Further, the fish showed an increased cough rate, which is more likely to be caused by a toxicant than by changes in normal water quality parameters (USEPA, 2001).

Although no incidents had been reported, an inspection of the area between the construction site and the reservoir effluent was conducted. A small oil sheen was reported at 11 a.m. The command center was notified, and a haz-

TABLE 2 Water quality at case study sites

Parameter	Large System*	Small System*
pH	7.0 (6.5–7.5)	7.7 (6.8–9.0)
Hardness—*mg/L as $CaCO_3$*	19 (17–21)	105 (34–160)
Temperature—*°C*	10.5 (1–21)	15.9 (3.2–27.2)
Specific conductivity—*µS/cm*	72 (60–86)	260 (97–377)
Turbidity—*ntu*	0.9 (0.7–1.4)	23.5 (2–589)

$CaCO_3$—calcium carbonate

*Average annual value (range)

ardous materials team cleaned the oil sheen. Water samples, retrieved from the autosampler that was triggered when the alarm occurred, were sent for analysis (USEPA, 1996). Results revealed 47 µg/L of diesel oil in the first sample. Without the biomonitor's response, the diesel fuel might have been dismissed as a small spill that could occur during a three-day weekend marked by storm events. It was estimated that a maximum of 5 gal of oil may have run off the barge used at the construction site. Figure 2 shows that physiological parameters monitored were different from the baseline but below the alarm threshold as early as 48 h before the alarm.

TABLE 3 Aquatic biomonitor 1-h response concentrations to toxicants

Estimated 1-h Response Concentration *mg/L*	Chemical	Reference
0.01–0.10	Brevetoxin	USEPA, 2001
	Residual chlorine*	Miller et al, 1980
	Cyanide	van der Schalie et al, 2004
>0.1–1.0	Carbaryl*	Carlson, 1990
	Mercury (Hg^{2+})	van der Schalie et al, 2004
	Metham sodium	van der Schalie et al, 2004
	Phosdrin	van der Schalie et al, 2004
	Zinc (Zn^{2+})	van der Schalie et al, 2004
>1.0–10.0	*p*-Chlorophenol	van der Schalie et al, 2004
	Malathion	van der Schalie et al, 2004
	Pentachlorophenol	van der Schalie et al, 2004
	1,1,2,2-Tetrachloroethane	van der Schalie et al, 2004
	Tetrachloroethylene*	Capute, 1980
>10.0–100.0	Chloroform*	Capute, 1980
	Phenol	van der Schalie et al, 2004
	Tricaine methanesulfonate	van der Schalie et al, 2004
>100	Acetone*	van der Schalie et al, 1979
	Meparfynol*	Carlson, 1990
	2,4-Pentanedione*	Carlson, 1990

*Effect level estimated from literature data on bluegill ventilatory responses; not measured using the aquatic biomonitor

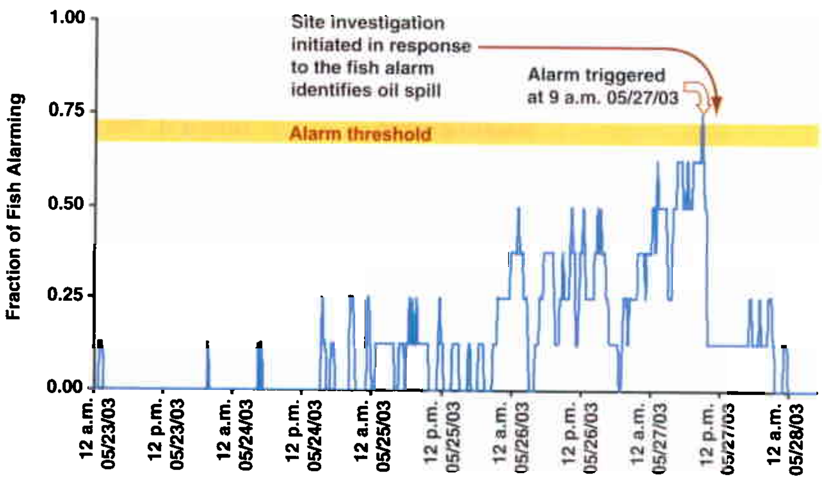
Small system. The water supply for this system is drawn from the lower Monocacy River Watershed (Frederick County), which covers approximately 304 sq mi (788 sq km) of predominantly agricultural land (MD DNR, 2003). The Monocacy River has relatively hard water that is highly variable in composition (Table 2). Marked daily fluctuations in temperature and dissolved oxygen and rapid changes in temperature and turbidity as a result of storms can occur. Water treatment includes flocculation followed by sedimentation, sand bed and carbon filtration, and chlorination. Water use is approximately 1.1 mgd (4,200 m^3/d). One side of the biomonitor received source water as it was pumped into the water treatment plant and the other side of the biomonitor received treated finished water that had been dechlorinated before passing through the biomonitor.

Early warning monitoring systems for source waters can provide rapid detection capabilities for accidental spills originating from nonpoint sources or point sources such as wastewater treatment plants, transportation incidents, and deliberate contamination events.

During the case study period from January to September 2004, the biomonitor was operational 98% of the time. Unscheduled downtime (1.5%) resulted from software malfunctions during initial software development, water quality multiprobe calibration issues, and accidental operator shutdowns. Routine downtime (0.5%) resulted from data archiving and fish change-out activities, as well as cleaning and maintenance activities required for the water dechlorination system. Routine maintenance of the biomonitor at this installation required approximately 4 h per week.

Infrequent nontoxicant-related alarms were caused by water quality probe malfunctions, water flow interruptions, and rapid temperature fluctuations. One apparent toxicant-related event occurred during the case study period (Figure 3), which began May 13, 2004, with alarms continuing over a period of several days. In this case, fish responded with greatly increased cough rates. Fish in the biomonitor chambers and the on-site holding

FIGURE 2 Toxicant alarm response at a reservoir effluent



the duration of exposure is long enough. Thus the issue is whether the response to a given chemical will occur soon enough and at a low enough concentration to provide useful information. Response characteristics of the aquatic biomonitor to chemicals tested in a control laboratory are shown in Table 3. Not surprisingly, ventilatory patterns of bluegills respond rapidly to chemicals that are highly acutely toxic and/or that cause direct gill damage, such as zinc or residual chlorine. Chemicals with low acute toxicity, such as some chemicals causing narcosis (e.g., acetone and meparfynol) require a higher exposure concentration to produce a rapid ventilatory response.

tank receiving raw Monocacy River water eventually died during the event. Significantly, fish in the biomonitor chamber that received the treated and dechlorinated water showed no increased stress and did not alarm at any time during the event, indicating that the toxicity was reduced by the treatment process and/or dilution to levels below those toxic to the fish.

Water obtained from the automated sampler over several days was evaluated to further define the nature of the toxicity. Water fleas (*Daphnia magna*) exposed to the sampled water for 24 h showed no mortality. Analysis of the water samples using a gas chromatograph/mass spectrometer (GC/MS) showed sporadic occurrences of the solvent butyl carbitol acetate and the herbicide metolachlor. Given this information and considering the time of year and the predominantly agricultural nature of the watershed, it is likely that the event was caused by one or both chemicals identified by GC/MS and used in herbicide or insecticide formulations, but the specific formulation responsible could not be definitively established.

BIOMONITOR IMPLEMENTATION CONSIDERATIONS

Although many factors are important for successful biomonitor operation (Gerhardt, 1999; LAWA, 1996; Hendriks & Stouten, 1993; Diamond et al, 1988), some key considerations for utilizing biomonitor systems for source water protection and distribution system monitoring include understanding biomonitor sensitivity to toxicants, minimizing false alarms because of nontoxicant-related factors, implementing biomonitor responses in an appropriate decision-making framework, and system costs.

Responsiveness to toxicants. A biomonitor will respond to any chemical if the concentration is high enough and

Toxicant sensitivity comparisons among the biomonitors listed in Table 1 are difficult because comparable response data are not available for many chemicals. However, it is unlikely that any one biomonitor is most sensitive (or most suitable) for all chemicals of concern. Although using multiple biomonitors has been recommended to improve overall response capabilities (LAWA, 1996; Kramer & Botterweg, 1991), increased expenses for the purchase and operation of multiple systems may make such an approach impractical.

Minimizing false alarms. Occasional biomonitor alarms unrelated to toxic events occurred at both sites. Such false alarms are not really false—the biomonitor tracked real fish responses to changes in environmental variables—but they are not related to contaminants in the water. Several common reasons exist for false alarms, and each can be reduced if not eliminated.

Loss of monitored water. Water loss most commonly occurs because the flow of source water stops (or because of reasons external to the biomonitor such as maintenance or clogged water lines). Water loss tends to be more of an issue at treatment plants (such as at the small system system) that use river water prone to high turbidity spikes following precipitation. Regular maintenance can help reduce failures. If water losses do occur, the design of the biomonitor keeps fish alive by recirculating water through the fish chambers, thus maintaining adequate dissolved oxygen levels.

Water quality multiprobe failures. Multiprobes may cause alarms by the expert system software if they go out of calibration or if a probe membrane fails. Regular maintenance of multiprobes is essential so that such problems are minimized.

System and human errors. As with any software system, it is possible to inadvertently shut down operation of the program. Training and experience are best for minimizing operator errors. Computer and operating system crashes have occurred, but their frequency has decreased with software upgrades. Uninterruptible power supplies are essential to prevent shutdown because of power loss. If a power loss does occur, the biomonitor keeps fish alive up to 48 h using a battery-powered aerator[8] that is triggered by a loss of water pressure in the water recirculation loop. Physical disturbance of the fish, such as excessive noise, can cause an alarm, but usually a large disturbance is required.

Natural water quality variations. If conductivity, dissolved oxygen, pH, and temperature change rapidly (over minutes or a few hours), they can cause biomonitor alarms. Fortunately, these water quality–related alarms can usually be identified as such by examining water quality and ventilatory data. More problematic is the issue of masking, which occurs when a toxicant is introduced at the same time as water quality is changing, such as when a pesticide is introduced into a stream by a precipitation event that alters temperature and dissolved oxygen.

Water quality–related alarms can be minimized in a number of ways. Temperature variations can be controlled by heating or cooling, low dissolved oxygen can be corrected through aeration, and high suspended solid loads can be removed by filtration. However, care must be taken not to alter the water matrix to the extent that toxicants capable of entering the water treatment process are removed.

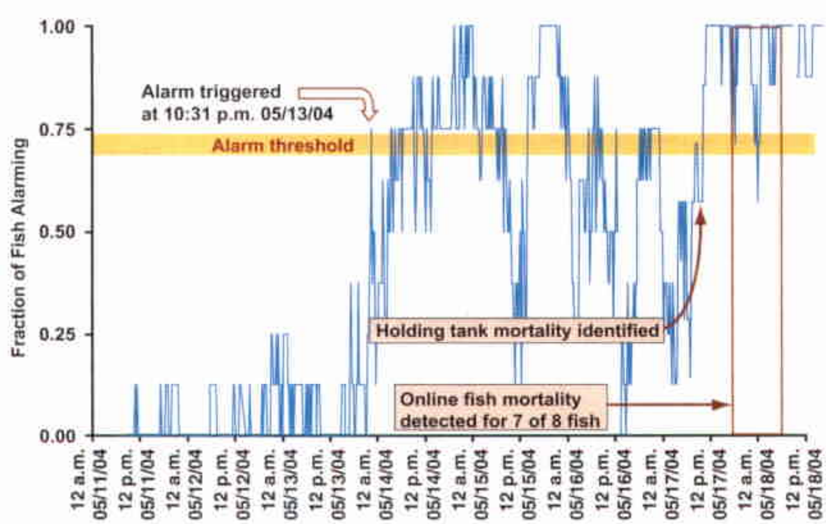
Sometimes the nature of the biomonitor response can help rule out water quality variations as the source of the alarm, as in the increased cough rate noted in the toxicant events. When the expert system software is used, false alarms can be reduced or eliminated by retraining the system using site-specific biomonitor data that includes fish responses to non-toxicant-related water quality variations gathered over time.

Interfering chemicals. Aquatic organisms are more sensitive to certain chemicals than are humans, so these chemicals may cause biomonitor alarms that are not indicative of potential harm to people. Residual chlorine, which is highly toxic to all aquatic organisms, must be removed before the use of any chlorinated water in a biomonitor. This was done to allow finished water monitoring at the small system water treatment plant. The dechlorination method was found to be effective for long-term biomonitor operation in chlorinated water but has not yet been tested in chloraminated water. Fish did not respond to the dechlorinating agent (sodium bisulfite) until concentrations reached eight times the normal dosing level (van der Schalie et al, 2005), but the effect of sodium bisulfite on biomonitor response to potential toxicants has not been determined. Another potential interference is copper, which can be associated with water treatment and distribution systems.

For interfering chemicals that are present continuously or on a recurring basis in the water being monitored, experience with the biomonitor can lead to improved identification and elimination of associated alarm events. The biomonitor can then focus attention on unusual alarm events that are of concern to water treatment plant operators.

Using biomonitors in a decision-making framework. A biomonitor is useful only if it supports sound decision-making. Biomonitor alarms are typically used in conjunction with available chemical monitoring data to trigger further analysis (Gunatilaka & Diehl, 2000; Kramer & Foekema, 2000). As with any early warning system in general (Gullick et al, 2003), a response plan must be put in place before a biomonitor alarm occurs. A formal decision framework should be implemented to deal with biomonitor alarms that involve all parties concerned with the response to a chemical contamination event. The response plan should outline followup procedures to ensure that alarm responses are proportional to the severity of the event.

FIGURE 2 Toxicant alarm response at the small system water treatment plant



After an alarm has occurred, the cause of the alarm should first be determined. Remote data examination can help rule out routine water quality variations or software errors. Site visits or communication with system operators can rule out other factors such as operational changes, physical disturbances, or equipment failures. If preliminary evaluation does not rule out the possibility of a toxic event, further causal evaluations may be undertaken. Confirmatory toxicity studies and other rapid analytical techniques (States et al, 2004) may be conducted, or, if sufficient time is available, more sophisticated and thorough analytical chemistry evaluations can be done. It may be useful to fractionate water samples (e.g., by carbon filtration to remove organics) so that individual fractions can be reevaluated using toxicity tests to identify the class(es) of chemicals associated with toxicity and to facilitate further analysis for specific chemical constituents (ILSI, 1999; USEPA, 1991).

Biomonitor costs. Biomonitors available commercially generally cost between \$10,000 and \$100,000. The aquatic biomonitor used in the case studies reported here cost approximately \$30,000. Costs continue to decline as computer and electronic components drop in price relative to increased capabilities. Maintenance for the fish biomonitor system and holding tanks is not excessive, requiring approximately 4 h per week. Routine monitoring checks of the data can be done within minutes via remote data communication or intranet/internet links.

CONCLUSION

Both of the case studies described in this article demonstrate that a biomonitor that uses sophisticated software to rapidly identify toxicity in water can be operated for extended periods of time with minimal maintenance and rare downtime. The biomonitor demonstrated the ability to detect common accidental surface water contaminants in source waters with different physical and chemical characteristics. A dechlorination device allows the biomonitor to be used for the continuous monitoring of chlorinated finished water. Finally, biomonitor deployment must include a response plan for event confirmation and notification.

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Research was conducted in compliance with the Animal Welfare Act and other federal statues and regulations relating to animals and experiments involving animals and adheres to principles stated in the Guide for the Care and Use of Laboratory Animals (NRC, 1996), in facilities that

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FOOTNOTES

[1]YSI 600XL Sonde, YSI Inc., Yellow Springs, Ohio, or Hydrolab H2O, Hach Co., Loveland, Colo.

[2]BioMonitor Expert, Intelligent Automation Corp., Poway, Calif.

[3]Intelligent Aquatic Biomonitoring System (iABS), IAC 1090, Intelligent Automation Corp., Poway, Calif.

[4]ISCO Refrigerated Sampler (Model 3700R), Teledyne Isco Inc., Lincoln, Neb.

[5]pcAnywhere, Symantec Corp., Cupertino, Calif.

[6]Sensaphone Model 1104, Sensaphone, Inc., Ashton, Pa.

[7]Portable dechlorinator, Geo-Centers, Inc., Newton, Mass.

[8]Bubbles of Life Series 2 aerator, Bubbles of Life, Inc., Balm, Fla., used with a Gem Sensor Pressure Switch (FS-500 Polypropylene, 3/4-in NPT, 0.25 GPM), Gem Sensors, Plainville, Conn.

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We are in the process of manually gathering data from our old system so that we can make comparisons with the new one, and I will be reporting the progress we've made in a future column. Human nature being what it is, there will probably still be delays. I remain optimistic, however, that all of the changes made to our peer review structure taken together will contribute toward reducing the overall amount of time a manuscript spends in peer review as well as toward strengthening the quality of manuscripts ultimately accepted for publication in the JOURNAL.

ERRATUM

In the January 2007 article by Cromwell and Speranza, "Asset Management Too Complicated? Just Think About Your Car," the wrong figure callouts were published with Figures 3 and 4. The correct callouts are:

Figure 3 Asset management plans help guard against arbitrary cuts in diagnostic and preventive maintenance spending

Figure 4 Asset management plans help guard against arbitrary cuts in rehabilitation and replacement spending